EXHIBIT 2

NFPA® 921

Guide for Fire and Explosion Investigations

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Guide for

Fire and Explosion Investigations

2021 Edition

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NOTICE: An asterisk (*) following the number or letter designating a paragraph indicates that explanatory material on the paragraph can be found in Annex A.

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Information on referenced and extracted publications can be found in Chapter 2 and Annex C.

Chapter 1 Administration

1.1 Scope. This document is designed to assist individuals who are charged with the responsibility of investigating and analyzing fire and explosion incidents and rendering opinions as to the origin, cause, responsibility, or prevention of such incidents and the damage and injuries that arise from such incidents.

1.1.1 The completion of reports for the United States National Fire Incident Reporting System (NFIRS) are outside the scope of this guide.

1.1.2 This guide considers NFIRS reports as incident reports and not as investigation reports. The information contained in an NFIRS report should generally be considered as the preliminary report of the fire department concerning any fire or explosion incident. An NFIRS report should not be used as a fire investigation report.

1.2 Purpose.

1.2.1 The purpose of this document is to establish guidelines and recommendations for the safe and systematic investigation or analysis of fire and explosion incidents. Fire investigation or analysis and the accurate listing of causes are fundamental to the protection of lives and property from the threat of hostile fire or explosions. It is through an efficient and accurate determination of the cause and responsibility that future fire incidents can be avoided. This document has been developed as a model for the advancement and practice of fire and explosion investigation, fire science, technology, and methodology.

1.2.2 Proper determination of fire origin and cause, as well as the cause of and responsibility for property damage, injuries, or deaths, is also essential for the meaningful compilation of fire statistics. Accurate statistics form part of the basis of fire prevention codes, standards, and training.

1.3 Application. This document is designed to produce a systematic, working framework or outline by which effective fire and explosion investigation and origin and cause analysis can be accomplished. It contains specific procedures to assist in the investigation of fires and explosions. These procedures represent the judgment developed from the NFPA consensus process system that if followed can improve the probability of reaching sound conclusions. Deviations from these procedures, however, are not necessarily wrong or inferior but need to be justified.

1.3.1 The reader should note that frequently the phrase *fire investigation* is used in this document when the context indicates that the relevant text refers to the investigation of both fires and explosions.

1.3.2 As every fire and explosion incident is in some way unique and different from any other, this document is not designed to encompass all the necessary components of a complete investigation or analysis of any one case. The scientific method, however, should be applied in every instance.

1.3.3 Not every portion of this document may be applicable to every fire or explosion incident. It is up to investigators (depending on their responsibility, as well as the purpose and scope of their investigation) to apply the appropriate recommended procedures in this guide to a particular incident.

1.3.4 In addition, it is recognized that the extent of the fire investigator's assignment, time and resource limitations, or existing policies may limit the degree to which the recommendations or techniques in this document will be applied in a given investigation.

Δ **1.3.5** This document is not intended as a comprehensive scientific or engineering text. Although many scientific and engineering concepts are presented within the text, the user is cautioned that additional technical resources, training, and education may often need to be utilized in an investigation.

1.4 Units of Measure. Metric units of measurement in this guide are in accordance with the modernized metric system known as the International System of Units (SI). The unit of liter is outside of but recognized by SI and is commonly used in international fire protection. These units are listed in Table 1.4.

 Shaded text = Revisions. Δ = Text deletions and figure/table revisions. • = Section deletions. *N* = New material.

3.3.67 Finish Rating. The time in minutes, determined under specific laboratory conditions, at which the stud or joist in contact with the exposed protective membrane in a protected combustible assembly reaches an average temperature rise of 121°C (250°F) or an individual temperature rise of 163°C (325°F) as measured behind the protective membrane nearest the fire on the plane of the wood.

3.3.68 Fire. A rapid oxidation process, which is an exothermic chemical reaction, resulting in the evolution of light and heat in varying intensities.

3.3.69 Fire Analysis. The process of determining the origin, cause, development, responsibility, and, when required, a failure analysis of a fire or explosion.

3.3.70 Fire Area. The boundary of fire effects within a scene in which the area of origin will be located. The fire area is characterized by identifying the border between damaged and undamaged areas, which are distinguishable by fire effects and patterns created by flame, heat, and smoke.

3.3.71 Fire Cause. The circumstances, conditions, or agencies that bring together a fuel, ignition source, and oxidizer (such as air or oxygen) resulting in a fire or a combustion explosion.

N **3.3.72* Fire Chemistry.** The study of chemical processes that occur in fires including changes of state, decomposition, and combustion.

3.3.73* Fire Dynamics. The detailed study of how chemistry, fire science, and the engineering disciplines of fluid mechanics and heat transfer interact to influence fire behavior.

3.3.74 Fire Effects. The observable or measurable changes in or on a material as a result of a fire.

3.3.75 Fire Hazard. Any situation, process, material, or condition that can cause a fire or explosion or that can provide a ready fuel supply to augment the spread or intensity of a fire or explosion, all of which pose a threat to life or property.

3.3.76 Fire Investigation. The process of determining the origin, cause, and development of a fire or explosion.

N **3.3.77* Fire Investigator.** An individual who has demonstrated the skills and knowledge necessary to conduct, coordinate, and complete a fire investigation. [1033, 2014]

3.3.78 Fire Patterns. The visible or measurable physical changes, or identifiable shapes, formed by a fire effect or group of fire effects.

3.3.79 Fire Propagation. See 3.3.82, Fire Spread.

3.3.80 Fire Scene Reconstruction. The process of recreating the physical scene during fire scene analysis investigation or through the removal of debris and the placement of contents or structural elements in their pre-fire positions.

3.3.81* Fire Science. The body of knowledge concerning the study of fire and related subjects (such as combustion, flame, products of combustion, heat release, heat transfer, fire and explosion chemistry, fire and explosion dynamics, thermodynamics, kinetics, fluid mechanics, fire safety) and their interaction with people, structures, and the environment.

3.3.82 Fire Spread. The movement of fire from one place to another.

3.3.83 First Fuel Ignited. The first fuel ignited is that which first sustains combustion beyond the ignition source.

3.3.84 Flame. A body or stream of gaseous material involved in the combustion process and emitting radiant energy at specific wavelength bands determined by the combustion chemistry of the fuel. In most cases, some portion of the emitted radiant energy is visible to the human eye. [72, 2019]

3.3.85 Flame Front. The flaming leading edge of a propagating combustion reaction zone.

Δ **3.3.86 Flameover.** The condition where unburned fuel (pyrolysate) from the originating fire has accumulated in the upper layer to a sufficient concentration (i.e., at or above the lower flammable limit) that it ignites and burns. This can occur without ignition of, or prior to the ignition of, other fuels separate from the origin.

3.3.87 Flammable. Capable of burning with a flame.

3.3.88 Flammable Limit. The upper or lower concentration limit at a specified temperature and pressure of a flammable gas or a vapor of an ignitible liquid and air, expressed as a percentage of fuel by volume that can be ignited.

3.3.89 Flammable Liquid. A liquid that has a closed-cup flash point that is below 37.8°C (100°F) and a maximum vapor pressure of 2068 mm Hg (40 psia) at 37.8°C (100°F). *(See also 3.3.34, Combustible Liquid.)*

3.3.90 Flammable Range. The range of concentrations between the lower and upper flammable limits. [68, 2018]

3.3.91 Flash Fire. A fire that spreads by means of a flame front rapidly through a diffuse fuel, such as dust, gas, or the vapors of an ignitible liquid, without the production of damaging pressure.

3.3.92 Flash Point of a Liquid. The lowest temperature of a liquid, as determined by specific laboratory tests, at which the liquid gives off vapors at a sufficient rate to support a momentary flame across its surface.

3.3.93 Flashover. A transition phase in the development of a compartment fire in which surfaces exposed to thermal radiation reach ignition temperature more or less simultaneously and, given sufficient availability of oxygen, fire spreads rapidly throughout the space, resulting in full room involvement or total involvement of the compartment or enclosed space.

3.3.94 Forensic (Forensic Science). The application of science to answer questions of interest to the legal system.

3.3.95 Fuel. A material that will maintain combustion under specified environmental conditions. [53, 2016]

3.3.96 Fuel Gas. Natural gas, manufactured gas, LP-Gas, and similar gases commonly used for commercial or residential purposes such as heating, cooling, or cooking.

3.3.97 Fuel Load. The total quantity of combustible contents of a building, space, or fire area, including interior finish and trim, expressed in heat units or the equivalent weight in wood.

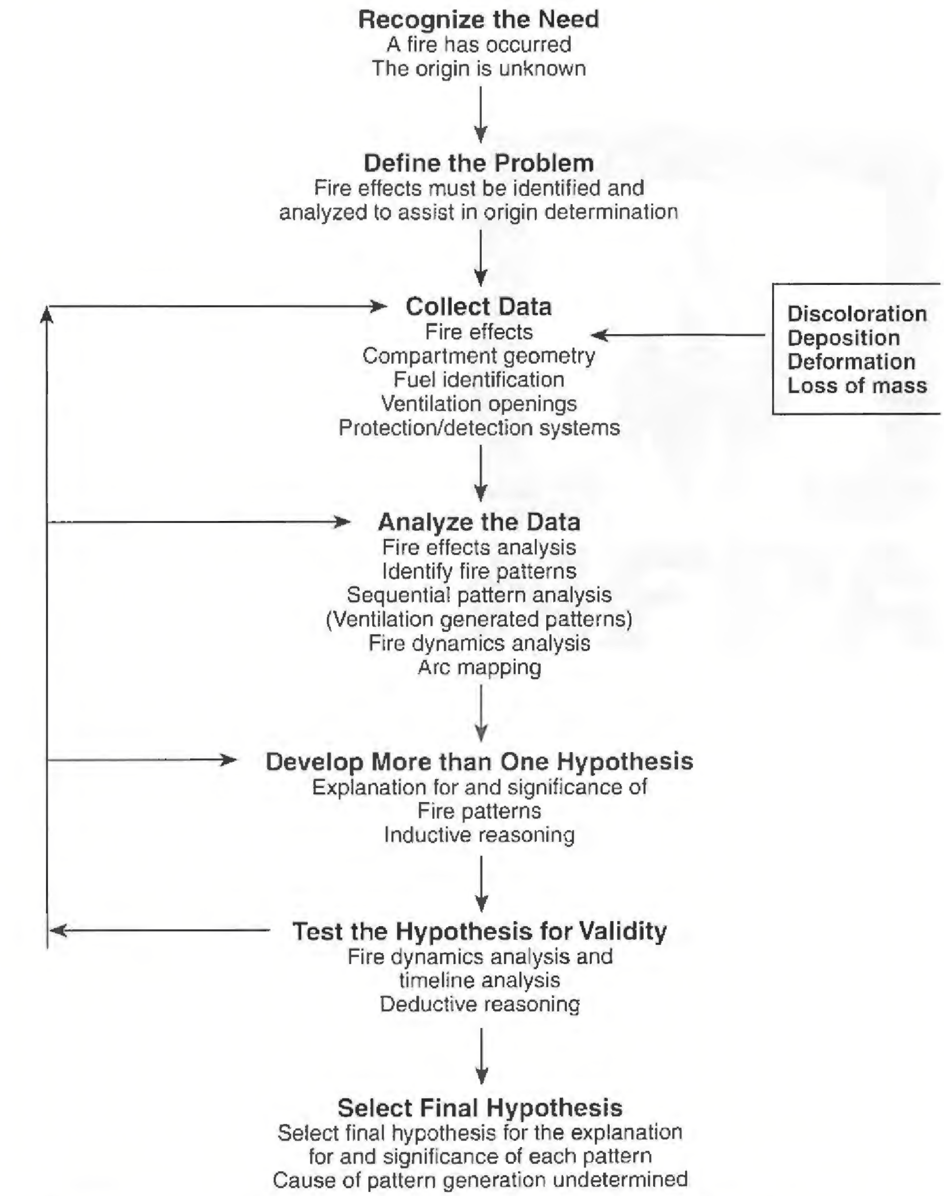
3.3.98 Fuel-Controlled Fire. A fire in which the heat release rate and growth rate are controlled by the characteristics of the fuel, such as quantity and geometry, and in which adequate air for combustion is available.

or progression of fire effects. After the data analysis, reasonable hypotheses can be developed.

N **6.1.5** Important data may not be included in the analysis if investigators look only for "patterns" within a fire scene. Investigators are cautioned not to make assumptions about how a pattern was created and then attribute meaning without performing a thorough analysis of all data collected. By noting basic observations, the differences in observations between various fire investigators concerning a basic fact set can be minimized. Following that portion of the investigation, additional data can be collected and further analysis can be conducted. See Figure 6.1.5.

• **6.2 Observations.** Fire investigators make observations of changes that may have resulted from fire conditions. Observations become the factual data set for analysis and interpretation that may lead to opinions about the nature of the fire that caused them. Observations may be qualitative or quantitative.

6.2.1 Fire Effects. As part of data collection, the investigator should be able to recognize the changes that have occurred in materials due to fire. These changes are referred to as fire effects, which are the observable or measurable changes in or on a material as the result of exposure to a fire. Common observations have been organized into four general categories where examples of routinely encountered fire effects have been arranged according to their fundamental observation. Many of the fire effects listed can be included in more than one category, but for simplicity they have been only listed in one category for the Table 6.2.1. Fire effects can be categorized based on the fundamental observation as shown in Table 6.2.1.



N **FIGURE 6.1.5 Example of Applying the Scientific Method to Fire Pattern Interpretation.**

FIGURE 6.3.20.10.2 Flash Fire Damage on Plastic Wrapper and Paper Roll.

Likewise, once secondary ignition occurs, the dynamics of the fire spread will be dictated by the compartment and fuel geometry and the relative heat release rates of these secondary fuels. The relatively short duration of the burning may have little impact on the flashover in the compartment as compared to the burning of the secondary fuels. Therefore, origin determination of such a flash fire can be supported by accurate witness observations and the analysis of the potential ignition sources in the areas where the vapor or gas could have existed. When the analysis of fire patterns is the only means of determining the origin, the investigator should be aware that the resultant ignition of secondary fuels and compartment flashover could have altered or obliterated the subtle patterns created by the flash fire.

6.3.20.10.2.2 The difficulty in detecting patterns caused by flash fires is the result of the total consumption of available fuel without significantly raising the temperatures of other combustibles. In this case, the fire patterns may be superficial and difficult to trace to any specific point of ignition as in Figure 6.3.20.10.2.2. In addition, separate areas of burning from pocket fuel gas may exist and further confuse the tracing of fire spread.

6.3.20.10.2.3 Saddle Burns. Saddle burns are distinctive U- or saddle-shaped patterns that are sometimes found on the top edges of floor joists. They are caused by fire burning downward through the floor above the affected joist. Saddle burns display deep charring, and the fire patterns are highly localized and gently curved. They also may be created by radiant heat from a burning material in close proximity to the floor, including materials that may melt and burn on the floor (e.g., polyurethane foam). Ventilation caused by floor openings may also contribute to the development of these patterns, shown in Figure 6.3.20.10.2.3.

N **6.3.21 Arc Mapping.** Arcing of electrical conductors in a fire can occur when two conditions are met: (1) there is a sufficient potential difference (voltage) and sufficient current available to the circuit in question, and (2) the intensity of the fire is severe enough to sufficiently damage the electrical insulation along an unintentional path between the conductors or conductive materials. Arc mapping is the identifying and documenting of fire patterns that constitute arcing of electrical conductors.

N **6.3.21.1 Interpretation of Arc Damage.** The propensity for arcing to occur is governed by the same primary factors as govern the formation of other combustion-related fire patterns.

N **6.3.21.2** Arc damage to a conductor is evidence that electric power was available at that locale, and the fire effects were sufficient to break down the insulation, resulting in electrical discharge. (This presumes that investigation has ruled out the possibility that arcing artifacts were created prior to the occurrence of the fire.)

N **6.3.21.3** Availability of electrical power and sufficient severity of fire are necessary but not sufficient conditions for arcing to occur. Research studies have demonstrated that arcing is a probabilistic event, and its occurrence or non-occurrence at a given location cannot be computed or predicted.

FIGURE 6.3.20.10.2.2 Blistering of Varnish on Door and Slight Scorching of Draperies, the Only Indications of the Natural Gas Flash Fire.

Δ **FIGURE 6.3.20.10.2.3 Saddle Burn in a Floor Joist.**

17.11.3.1 Certainly, the fire investigator will not always have the opportunity to determine the quantity of physical evidence he or she can collect. Often, the fire investigator can collect only that quantity that is discovered during his or her investigation.

17.11.3.2 Each laboratory examination or test requires a certain minimum quantity of physical evidence to facilitate proper and accurate results. The fire investigator should be familiar with these minimum requirements. The laboratory that examines or tests the physical evidence should be consulted concerning these minimum quantities.

17.11.4 Comparative Examination and Testing.

17.11.4.1 During the course of certain fire investigations, the fire investigator may wish to have appliances, electrical equipment, or other products examined to determine their compliance with recognized standards. Such standards are published by the American Society for Testing and Materials, Underwriters Laboratories Inc., and other agencies.

17.11.4.2 Another method of comparative examination and testing involves the use of an exemplar appliance or product. Utilizing an exemplar allows the testing of an undamaged example of a particular appliance or product to determine whether it was capable of causing the fire. The sample should be the same make and model as the product involved in the fire.

17.12 Evidence Disposition.

17.12.1 The fire investigator is often faced with disposing of evidence after an investigation has been completed. The investigator should not destroy or discard evidence unless proper authorization is received. Circumstances may require that evidence be retained for many years and ultimately may be returned to the owner.

17.12.2 Criminal cases such as arson require that the evidence be kept until the case is adjudicated. During the trial, evidence submitted — such as reports, photographs, diagrams, and items of physical evidence — will become part of the court record and will be kept by the courts. Volatile or large physical items may be returned to the investigator by the court. There may be other evidence still in the investigator's possession that was not used in the trial. Once all appeals have been exhausted, the investigator may petition the court to either destroy or distribute all of the evidence accordingly. A written record of authorization to dispose of the evidence should be kept. The criminal investigator should be mindful of potential civil cases resulting from this incident, which may require retention of the evidence beyond the criminal proceedings.

Chapter 18 Origin Determination

Δ **18.1 Introduction.** This chapter recommends a methodology to follow in determining the origin of a fire. The origin of a fire is one of the most important hypotheses that an investigator develops and tests during the investigation. Generally, if the origin cannot be determined, the cause cannot be determined, and generally, if the correct origin is not identified, the subsequent cause determination will also be incorrect. The purpose of determining the origin of the fire is to identify in three dimensions the locations at which the fire began.

18.1.1 This chapter deals primarily with the determination of origin involving structures; however, the methodology generally applies to all origin determinations. Separate chapters address the particular requirements for determining origin in nonstructure fire incidents (motor vehicles, boats, wildfire, etc.).

Δ **18.1.2** Determination of the origin of the fire involves the coordination of information derived from one or more of the following:

(1) *Witness Information and/or Electronic Data.* The analysis of observations reported by persons who witnessed the fire or were aware of conditions present at the time of the fire as well as the analysis of electronic data including but not limited to security camera footage, alarm system activation, or other such data recorded in and around the time of the fire event *(see Chapter 14)*

(2) *Fire Patterns.* The analysis of effects and patterns left by the fire, which may include patterns involving electrical conductors *(see Chapter 6)*

(3) *Fire Dynamics.* The analysis of the fire dynamics [i.e., the physics and chemistry of fire initiation and growth *(see Chapter 5)* and the interaction between the fire and the building's systems *(see Chapter 7)*]

Δ **18.2 Overall Methodology.** The overall methodology for determining the origin of the fire is the scientific method as described in Chapter 4. This methodology includes recognizing and defining the problem to be solved, collecting data, analyzing the data, developing hypotheses, and most importantly, testing the hypothesis or hypotheses. In order to use the scientific method, the investigator must develop at least one hypothesis based on the data available at the time. These hypotheses should be considered "working hypotheses," which upon testing may be discarded, revised, or expanded in detail as new data is collected during the investigation and new analyses are applied. This process is repeated as new information becomes available. *(See Figure 18.2.)*

18.2.1 Testing any origin hypothesis requires an understanding of the associated fire events as well as the growth of the fire and how the fire spread through the structure. A narrow focus on only identifying the first item ignited and a competent ignition source fails to take into account important data that can be used to test any origin hypothesis. In such a narrow focus, the growth and spread of the fire and the resulting fire damage are not well considered.

18.2.1.1 The purpose of the fire spread analysis is to determine whether the resulting physical damage and available data are consistent with the area of origin hypothesis. For example, a fire starting in a wastebasket is a plausible working hypothesis, but the resulting fire damage would be highly dependent on the position of the first fuel and any subsequently ignited fuels. If the wastebasket had been located in an area with no adjacent fuel, then the results may be significantly different than if the wastebasket had been located next to a polyurethane sofa. Both hypotheses posit the same first item ignited, but the outcome is very different. Thus, if the origin hypothesis is not consistent with the resulting growth and spread of the fire, it is not a valid hypothesis. Fire spread scenarios within a compartment or building should be analyzed using the principles of fire dynamics presented in Chapter 5 and fire pattern development in Chapter 6.

18.2.1.2 In some instances, a single item, such as an irrefutable article of physical evidence or a credible eyewitness to the

also identify gaps or inconsistencies in the data. The utility of fire dynamics tools is not limited to hypothesis testing. They may also be used for data analysis and hypothesis development. Techniques and tools include time line analysis, fire dynamics analysis, and experimentation.

18.6.2.1 Time Line Analysis. Time lines are an investigative tool that can show relationships between events and conditions associated with the fire. These events and conditions are generally time-dependent, and thus, the sequence of events can be used for testing origin hypotheses. Relevant events and conditions include ignition of additional fuel packages, changes in ventilation, activation of heat and smoke detectors, flashover, window breakage, and fire spread to adjacent compartments. Much of this information will come from witnesses. Fire dynamics analytical tools *(see 21.4.8)* can be used to estimate time-dependent events and fire conditions. A more detailed discussion of time lines is included in Section 21.2.

18.6.2.2 Fire Modeling. Fundamentals of fire dynamics can be used to test hypotheses regarding fire origin. Such fundamentals are described in the available scientific literature and are incorporated into fire models ranging from simple algebraic equations to more complex computer fire models *(see 21.4.8)*. The models use incident-specific data to predict the fire environment given a proposed hypothesis. The results can be compared to physical and eyewitness evidence to test the origin hypothesis. Models can address issues related to fire development, spread, and occupant exposure.

18.6.2.3 Experimental Testing. Experimental testing can be conducted to test origin hypotheses. If the experimental testing results are substantially similar to the damage at the scene, the experimental data can be said to be consistent with the origin hypothesis. If the experimental testing produces results that are not substantially similar with the damage, an alternative origin hypothesis or additional data may need to be considered, taking into account potential differences between the experimental testing and the actual fire conditions. The following is an example of such an experiment. The hypothesized origin is a wicker basket located in the corner of a wood-paneled room. The data from the actual fire shows the partial remains of the wicker basket, undamaged carpet in the corner, and wood paneling still intact in the corner. A fire test replicating the hypothesized origin totally consumes the carpet, the wicker basket, and the wood paneling. Thus (assuming the test replicated the pre-fire conditions), testing revealed that this hypothesized origin is inconsistent with the damage that would be expected from such a fire.

18.7 Selecting the Final Hypothesis. Once the hypotheses regarding the origin of the fire have been tested, the investigator should review the entire process, to ensure that all credible data are accounted for and all credible alternate origin hypotheses have been considered and eliminated. When using the scientific method, the failure to consider alternate hypotheses is a serious error. A critical question to be answered by fire investigators is, "Are there any other origin hypotheses that are consistent with the data?" The investigator should document the facts that support the origin determination to the exclusion of all other potential origins.

18.7.1 Defining the Area of Origin. Although *area of origin* is common terminology used to describe the origin, the investigator should describe it in terms of the three-dimensional space where the fire began, including the boundaries of that space.

18.7.2 Inconsistent Data. It is unusual for a hypothesis to be totally consistent with all of the data. Each piece of data should be analyzed for its reliability and value — not all data in an analysis has the same value. Frequently, some fire pattern or witness statement will provide data that appears to be inconsistent. Contradictory data should be recognized and resolved. Incomplete data may make this difficult or impossible. If resolution is not possible, then the origin hypothesis should be re-evaluated.

18.7.3 Case File Review. Other investigators can assist in the evaluation of the origin hypothesis. An investigator should be able to provide the data and analyses to another investigator, who should be able to reach the same conclusion as to the origin. Review by other investigators is almost certain to happen in any significant fire case. Differences in opinions may arise from the weight given to certain data by different investigators or the application of differing theoretical explanations (fire dynamics) to the underlying facts in a particular case.

18.8 Origin Insufficiently Defined. There are occasions when it is not possible to form a testable hypothesis defining an area that is useful for identifying potential causes. The goal of origin investigation is to identify the precise location where the fire began. In practice, the investigator has an origin hypothesis when first arriving at a fire scene. The origin is the scene. Sometimes, it is not possible to find an area or volume that is any smaller than the entire scene. Thus, a conclusion of the origin investigation can be the identification of a volume of space too large to identify causal factors, or where no practical boundaries can be established around the volume of the origin. An example of such an origin can be a building that has been totally burned, with no eyewitnesses. Such fires are sometimes called total burns. The area of origin is the building, but in reality no further testable origin hypothesis can be developed because there is insufficient reliable data.

18.8.1 Large Area Adequate for Determination. There are cases in which a lack of an origin determination does not necessarily hinder the investigation. An example is a case in which a fire resulted from the ignition of fuel gas vapors inside a structure. The resulting damage may preclude the defining of the location where the fuel combined with the ignition source. However, probable ignition sources may still be hypothesized.

18.8.2 Justification of a Large Area of Origin. The origin analysis should identify the data that justify the conclusion that the area of fire origin cannot be reduced to a practical size. Examples of such data could include establishing the fact that there were no significant patterns to trace, that most or all combustible materials were consumed, or that other methods of origin determination were attempted but no reasonable conclusion could be established.

18.8.3 Eyewitness Evidence of Origin Area. If the origin is too large to be useful, then the determination of the fire's cause may become very difficult, or impossible. In some instances, where no further testable origin hypothesis can be developed by examination of the scene alone, a witness may be found who saw the fire in its incipient stage and can provide the investigator with an area of fire origin.

their original form so that they can be used and examined via software intended for that purpose. Files should not be provided as scans or facsimiles, where the ability to use or examine the results via software is limited. As with all discovery issues, parties are free to litigate the reasonableness of the scope of discovery, cost sharing, the burden of production, and the protection of proprietary or trade secrets. Courts can fashion remedies that accommodate and protect the interests of all parties.

21.4.2 Heat Transfer Analysis.

21.4.2.1 Heat transfer models allow quantitative analysis of conduction, convection, and radiation in fire scenarios. These models are then used to test hypotheses regarding fire causation, fire spread, and resultant damage to property and injury to people. Heat transfer models are often incorporated into other models, including structural and fire dynamics analysis. Various general texts on heat transfer analysis are available.

21.4.2.2 Heat transfer models and analyses can be used to evaluate various hypotheses, including those relating to the following:

(1) Competency of ignition source *(See Section 19.3.)*
(2) Damage or ignition to adjacent building(s)
(3) Ignition of secondary fuel items
(4) Thermal transmission through building elements

21.4.3 Flammable Gas Concentrations. Models can be used to calculate gas concentrations as a function of time and elevation in the space and can assist in identifying ignition sources. Flammable gas concentration modeling, combined with an evaluation of explosion or fire damage and the location of possible ignition sources, can be used (a) to establish whether or not a suspected or alleged leak could have been the cause of an explosion or fire, and (b) to determine what source(s) of gas or fuel vapor were consistent with the explosion or fire scenario, damage, and possible ignition sources.

21.4.4 Hydraulic Analysis.

21.4.4.1 Analysis of automatic sprinkler and water supply systems is often required in the evaluation of the cause of loss. The same mathematical models and computer codes used to design these systems can be used in loss analysis. However, the methods of application are different for design than they are for forensic analysis.

21.4.4.2 A common application of hydraulic analysis is to determine why a sprinkler system did not control a fire. Modeling can also be used to investigate the loss associated with a single sprinkler head opening, to investigate the effect of fouling in the piping, and to determine the effect of valve position on system performance at the time of loss. There are also models and methods available to analyze flow through systems other than water-based systems, such as carbon dioxide, gaseous suppression agents, dry chemicals, and fuels.

21.4.5 Thermodynamic Chemical Equilibrium Analysis. Fires and explosions believed to be caused by reactions of known or suspected chemical mixtures can be investigated by a thermodynamics analysis of the probable chemical mixtures and potential contaminants.

21.4.5.1 Thermodynamic chemical equilibrium analysis can be used to evaluate various hypotheses, including those relating to the following:

(1) Reaction(s) that could have caused the fire/explosion
(2) Improper mixture of chemicals
(3) Role of contamination
(4) Role of ambient conditions
(5) Potential of a chemical or chemical mixture to overheat
(6) Potential for a chemical or chemical mixture to produce flammable vapors or gases
(7) Role of human action on process failures

21.4.5.2 Thermodynamic reaction equilibrium analysis traditionally required tedious hand calculations. Currently available computer programs make this analysis much easier to perform. The computer programs typically require several material properties as inputs, including chemical formula, mass, density, entropy, and heat of formation.

21.4.5.3 Chemical reactions that are shown not to be favored by thermodynamics can be eliminated from consideration as the cause of a fire. Thermodynamically favored reactions must be further analyzed to determine whether the kinetic rate of the considered reactions is fast enough to have caused ignition, given the particular circumstances of the fire.

21.4.6 Structural Analysis. Structural analysis techniques can be utilized to determine reasons for structural failure or change during a fire or explosion. Numerous references can be found in engineering libraries, addressing matters such as strength of materials, formulas for simple structural elements, and structural analysis of assemblies.

21.4.7* Egress Analysis. The failure of occupants to escape may be one of the critical issues that an investigator needs to address. Egress models can be utilized to analyze movement of occupants under fire conditions. Integrating egress models with a fire dynamics model is often necessary to evaluate the effect of the fire environment on the occupants. See Section 11.3 on human factors.

21.4.8* Fire Dynamics Analysis. Fire dynamics analyses consist of mathematical equations derived from fundamental scientific principles or from empirical data. They range from simple algebraic equations to computer models incorporating many individual fire dynamics equations. Fire dynamics analysis can be used to predict fire phenomena and characteristics of the environment such as the following:

(1) Time to flashover
(2) Gas temperatures
(3) Gas concentrations (oxygen, carbon monoxide, carbon dioxide, and others)
(4) Smoke concentrations
(5) Flow rates of smoke, gases, and unburned fuel
(6) Temperatures of the walls, ceiling, and floor
(7) Time of activation of smoke detectors, heat detectors, and sprinklers
(8) Effects of opening or closing doors, breakage of windows, or other physical events

21.4.8.1 Fire dynamics analyses can be used to evaluate hypotheses regarding fire origin and fire development. The analyses use building data and fire dynamics principles and data to predict the environment created by the fire under a proposed hypothesis. The results can be compared to physical and eyewitness evidence to support or refute the hypothesis.

21.4.8.2 Building, contents, and fire dynamics data are subject to uncertainties. The effects of these uncertainties should be assessed through a sensitivity analysis and should be incorpora-